Normative Models and Healthcare Planning: Network-Based Simulations Within a Geographic Information System Environment

Stephen J. Walsh, Philip H. Page, and Wilbert M. Gesler

Objectives. Network analysis to integrate patient, transportation, and hospital characteristics for healthcare planning in order to assess the role of geographic information systems (GIS). A normative model of base-level responses of patient flows to hospitals, based on estimated travel times, was developed for this purpose.
Data Sources/Study Setting. A GIS database developed to include patient discharge data, locations of hospitals, US TIGER/Line files of the transportation network, enhanced address-range data, and U.S. Census variables. The study area included a 16-county region centered on the city of Charlotte and Mecklenburg County, North Carolina, and contained 25 hospitals serving nearly 2 million people over a geographic area of nearly 9,000 square miles.
Study Design. Normative models as a tool for healthcare planning were derived through a spatial Network analysis and a distance optimization model that was implemented within a GIS. Scenarios were developed and tested that involved patient discharge data geocoded to the five-digit zip code, hospital locations geocoded to their individual addresses, and a transportation network of varying road types and corresponding estimated travel speeds to examine both patient discharge levels and a doubling of discharge levels associated with total discharges and DRG 391 (Normal Newborns). The Network analysis used location/allocation modeling to optimize for travel time and integrated measures of supply, demand, and impedance.
Data Collection/Extraction Methods. Patient discharge data from the North Carolina Medical Database Commission, address-ranges from the North Carolina Institute for Transportation Research and Education, and U.S. Census TIGER/Line files were entered into the ARC/INFO GIS software system for analysis. A relational database structure was used to organize the information and to link spatial features to their attributes.
Principal Findings. Advances in healthcare planning can be achieved by examining baseline responses of patient flows to distance optimization simulations and healthcare scenarios conducted within a spatial context that uses a normative model to integrate characteristics of population, patients, hospitals, and transportation networks. Model runs for the defined scenarios indicated that a doubling of the 1991 patient discharge levels resulted in an areal constriction of the service areas to those zip codes immedi-

ately adjacent to the hospitals, thereby leaving substantial areas unassigned to hospitals during the allocation process, but that doubling the demand for obstetrics care (DRG 391) resulted in little change in the pattern of accessibility to care as indicated by the size, orientation, and pattern of the service areas.

Conclusions. The GIS–Network system supported "what if" simulations, portrayed service areas within a spatial context, integrated disparate data in the execution of the location/allocation model, and used estimated travel time along a transportation network instead of Euclidean distance for calculating accessibility. The results of the simulations suggest that the GIS–Network system is an effective approach for exploring a variety of healthcare scenarios where changes in the supply, demand, and impedance variables can be examined within a spatial context and where variations in system trajectories can be simulated and observed.

Key Words. Geographic information systems, spatial network analysis, normative model for healthcare planning

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The use of geographic information systems (GIS) in health-related studies is emerging as an important new tool in healthcare planning and research (Albert, Gesler, and Wittie 1995). While medical geographers and others have long employed spatial analytical techniques to address healthcare questions (Shannon and Dever 1974; Morrill and Earickson 1968; Griffith, Restuccia, Tedeschi, et al. 1981; Cohen and Lee 1985; Gesler 1986), GIS offers an automated and integrative system that operates within a spatial context, where input, storage, retrieval, analysis, and display subsystems support spatial and nonspatial inquiry (Francis and Schneider 1984; Curtis 1989; Twigg 1990; Albert, Gesler, and Wittie 1995). GIS is further defined through its component parts: hardware, software, spatial data, geographic theory, and personnel trained in the resident system and spatial concepts. Tools and techniques are

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Address all correspondence and requests for reprints to Stephen J. Walsh, Ph.D., Director, Spatial Analysis Laboratory, Department of Geography, Senior Research Fellow, Sheps Center for Health Services Research, University of North Carolina, Chapel Hill, NC 27599–3220. Philip H. Page, M.A. is Research Associate, Spatial Analysis Unit, Carolina Population Center, UNC; and Wilbert M. Gesler, Ph.D. is George J. Kane Professor of Geography and Senior Research Fellow, Sheps Center, UNC. This article, submitted to *Health Services Research* on February 12, 1996, was revised and accepted for publication on September 18, 1996.

now available whereby actual and simulated spatial patterns of healthcare use, competition, and accessibility are able to be generated for individual hospitals and hospital networks that serve single and multiple counties (Walsh et al. 1995a).

Several researchers have begun exploring the use of GIS and its associated tools and techniques for healthcare studies (Twigg 1990; Matthews 1990; Mott et al. 1995). Research has tended to focus on special-purpose GIS analyses such as: routing and emergency planning (Dunn 1992); locality planning (Curtis 1989); assessing exposure boundaries and populations at risk (Stallones, Nichols, and Berry 1992); generating spatial linkages between healthcare providers and consumers (Verhasselt 1993); and characterizing hospital service areas (McLafferty 1988; Wrigley 1991; Zwarenstein, Krige, and Wolff 1991; Gesler, Walsh, Crawford, et al. 1995). Others have assessed the capability of a GIS to integrate large volumes of information for planning and research questions (Lam 1986); apply concepts of access and population potentials (Rosero-Bixby 1993); and employ Central Place theory (Gesler, Walsh, Crawford, et al. 1995) in the study of healthcare accessibility.

Few studies have been used to examine the use of normative models as a tool for healthcare planning within a GIS context. Recently, however, Walsh et al. (1995a and 1995b) used a GIS to perform location/allocation modeling of healthcare accessibility through network analysis and hospital use indexes; Evans et al. (1995) used GIS and Network analysis techniques to assess the geographic accessibility of rural Thailand villages to healthcare facilities by exploring the impact of travel alternatives and assumptions regarding the performance of the network routing optimization, and Gesler, Walsh, Crawford, et al. (1995) used GIS to assess hospital service areas through derivation of geographic distance, geographical boundaries, and patient origins.

The basic intent of this research is to assess the role of GIS and Network analysis for defining hospital service areas for 25 hospitals that are located within a 16-county North Carolina region by mapping actual 1991 total patient discharges geocoded to the zip code level and DRG-related patient discharges also geocoded to the zip code level, and by simulating new service areas by doubling patient demand. To that end, a GIS database was developed where hospitals, patients, and transportation networks were organized within a spatial analytical system that integrated measures of supply, demand, and impedance in the calculation of a normative model of healthcare accessibility. The research is cast within a healthcare planning context, but the goals of the research are to examine the spatial analytical potentials of GIS and Network analysis for characterizing service areas and generating normative models through mapping and simulation procedures respectively. The derived normative models implicitly assume that all patients can be treated at all hospitals and that patient travel time is the primary decision factor in the selection or allocation of patients to hospitals for healthcare. We are keenly aware, however, that other factors in addition to travel time are involved in the selection of healthcare locations: such factors could also be modeled through the methodologies discussed here, but a demonstration of GIS and Network analysis for healthcare planning was the preeminent objective of the research, and therefore the use of a single patient selection factor was deemed sufficient. Also, DRG 391 (Normal Newborns) was used to focus on service areas associated with a specific type of healthcare provided at a reduced number of hospitals (down from 25 to 19 hospitals that provided obstetrics care) within the study area. It is important to note that any DRG or product line, at any level (primary, secondary, or tertiary) of service and for individual hospitals, hospital clusters, or for all hospitals within the study region could be examined through the following methodologies.

METHODS

Location/allocation modeling has been used by geographers, medical geographers in particular, since the 1960s. Scott (1970) provides a good overview of the basic problems and their solutions. Specific applications of location/allocation models in the healthcare field include the development of alternative scenarios for locating new hospitals and allocating populations to them (Godlund 1961); assignment of hospitals services (Gould and Leinbach 1966); locating primary care health centers for the undoctored population (Bennett 1981); locating a new hospital (Mohan 1983); and developing strategies to locate a series of healthcare facilities by taking both facility capacity and distance minimization into account (Rushton 1975). In associated work, Luft, Garnick, Mark, et al. (1990) used conditional logit models to examine the effect of distance and other factors on the choice of hospitals. They found that greater distance between patients and hospitals consistently reduced the likelihood of hospital selection. Phibbs and Luft (1995) showed that straight-line distance and travel time are highly correlated in most hospital demand or choice models except in studies that focus on specific hospitals, very small numbers of hospitals, or studies in dense urban environments where traffic congestion could significantly constrain access to care. All of these studies were carried out without the benefit of GIS technologies and tended to focus more on depicting spatial processes than on characterizing the linkage and nodality of networks (Gesler 1986).

Network analysis, as used in this research, is an approach of routing and allocating resource flows through a system connected by a set of linear features (e.g., roads and trails), where distance optimization decisions within the network are made dependent on (a) the nature of the travel conduits; (b) links between conduits; (c) location and characteristics of barriers to movement; (d) directionality of resource flows, position, and conditions of centers having specific resource capacities; and (e) node locations, where resources are deposited or collected along paths throughout the network (Lupien, Moreland, and Dangermond 1987; Environmental Systems Research Institute 1992; Walsh et al. 1995b). In this research, Network analysis was used to select the "best" route through a network by determining the optimal paths for movement through a distance (travel time) optimization algorithm. The pathfinding program used for route selection operates through user-defined specifications of origin, destination, and stops or nodes along the network that might affect the optimization of the resource flow. Nodes are used to indicate road intersections and the location along a road segment where changes in road type (e.g., paved to unpaved) or road class (e.g., number of lanes) occur.

Network analysis integrates measures of supply, demand, and impedance to measure accessibility and to model resource allocations. *Supply* refers to the capacity of a facility to meet healthcare needs as indicated, for example, by the number of available hospital beds or the number of attending physicians. *Demand* quantifies the degree of hospital use as the allocation is performed, whereas *impedance* is the travel cost between patients and hospital locations. Travel costs can be determined by geographic distance or other factors. In this research, travel time, based on distance and estimated average travel speed along each link, was used as the impedance variable. *Allocation* is the process of assigning links in the network to the closest hospital along the optimal path between each link and the hospital. As links are assigned to a hospital, a portion of that hospital's resources are distributed to meet each link's demand. Allocation continues until the maximum impedance limit is reached along all the paths allocated to the hospital, or until the hospital's resource capacity (e.g., number of beds) is met by the cumulative demand from all links allocated to the hospital.

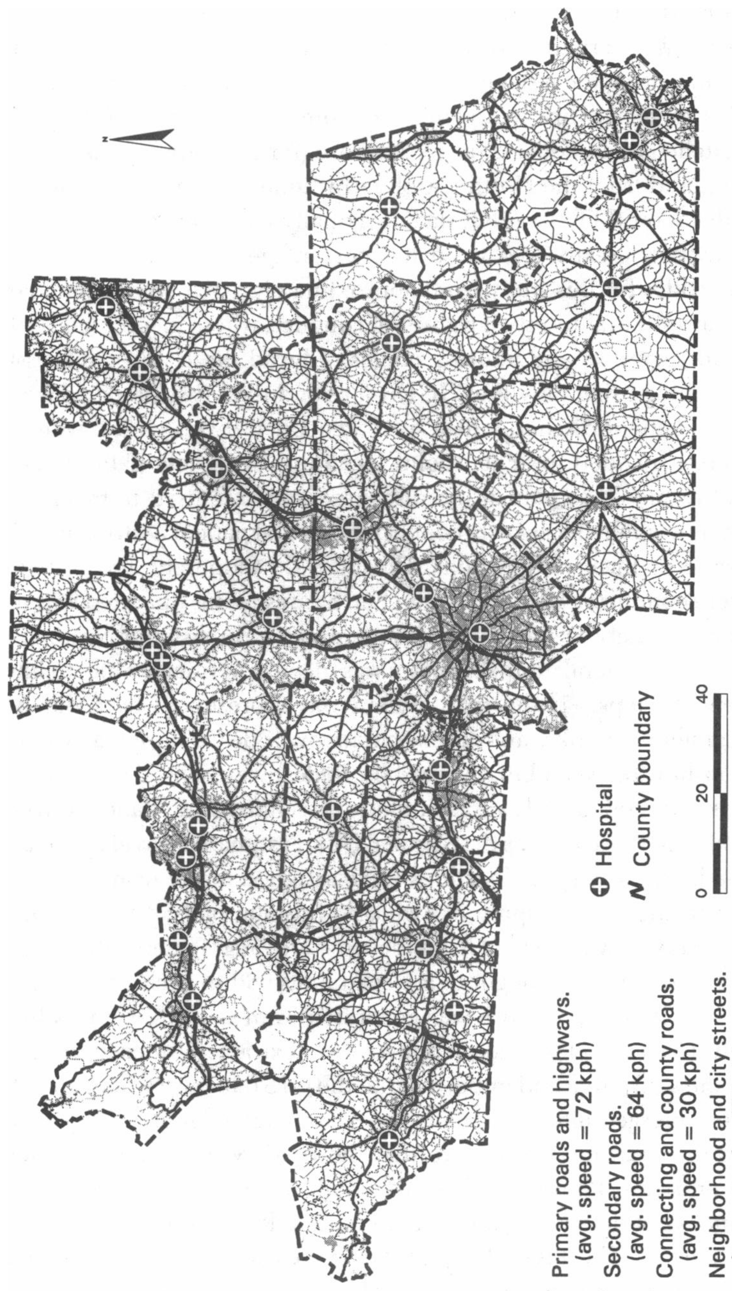
In this research, route or pathway modeling procedures were implemented within the NETWORK module of the ARC/INFO GIS software package to determine travel times to hospitals. Estimated average speeds were assigned to each road segment based on road type derived from U.S. Census

TIGER/Line files. Travel time for each road segment was then calculated using the estimated average speeds and the road segment length. Paths of optimal travel time were derived between each hospital and the patient discharges aggregated at the five-digit zip codes using a pathfinding algorithm developed by Dijkstra (1959) and implemented within ARC/INFO. This algorithm finds the optimal, least-cost path between two points in a transportation network based on transportation attributes such as path length or trip time. Route selection is defined by starting with a defined origin position along the network (e.g., zip code) where possible travel paths are defined and evaluated for minimization of travel through a distance optimization algorithm. As each intermediate node between links is identified, the minimum cost path of the preceding links and nodes is assigned and summed when the final destination is reached. Travel times are accumulated for the minimum travel routes for each of the user-defined points and centers.

The analyses relied on (a) the structural properties of the vector data model to represent a road transportation system and associated origins and destinations, and (b) the Network analysis capabilities of the GIS to allocate patients (i.e., the demand for healthcare resources at the origins) to hospitals (i.e., supply of resources at the destinations) based on impedances to travel (i.e., distance and road travel speeds) along the road system (Environmental Systems Research Institute 1992; Laurini and Thompson 1992). The goal of the allocation process was to assign patients to hospitals in a manner that would minimize each patient's travel time to care.

A GIS database was constructed for a 16-county area in North Carolina, centered on Charlotte and Mecklenburg County. (Note that for actual healthcare planning studies using Network analysis, the study area should not constrain the analysis by imposing arbitrary political borders on the source and flow of patients to and from hospitals within and outside the defined study area [See Openshaw 1984; Flowerdew and Green 1989; and Bracken 1994.]) The database consisted of (a) boundary files that defined county borders and five-digit zip codes; (b) point locations of 25 hospitals with associated supply characteristics (i.e., number of beds); (c) geocoded addresses of patient discharges summarized at the five-digit zip code; and (d) transportation patterns and road classifications. Figure 1 presents the central elements of the GIS database with particular emphasis on the transportation network used for patient allocation to specific hospitals. These data were compiled as part of a grant awarded by the Department of Housing and Urban Development to the Charlotte-Mecklenburg Hospital Authority for the purpose of designing an urban-rural healthcare network. The database could have been altered to

Figure 1: Study Area Road Network



support analyses involving different travel conditions and/or times of day by assigning alternative travel speeds to road types, by varying road types, and/or by including the influence of new road construction on the Network analysis. The road network was generated from U.S. Census TIGER/Line files and matched to an address range database (for geocoding patients and hospitals) acquired from the North Carolina Institute for Transportation Research and Education (ITRE). ITRE data, originally customized for school bus routing activities, greatly expanded the percentage of successful patient discharge geocodes for this study from approximately 40 to 90 percent, particularly in rural and rural-to-urban transition counties, where incomplete and/or missing road segments and address ranges reduced the level of successful address-matching using only the TIGER files and their associated address ranges.

Patient discharge data were geocoded to zip codes, whereas hospitals were geocoded to actual point locations. Complete patient addresses were not available as part of the discharge database used in this research. Some studies would necessarily benefit from actual patient address-matching to their home or business locations. Database development and Network analyses were conducted in this study on Sun Sparcstations operated within the Spatial Analysis Lab, Department of Geography, University of North Carolina.

In general, the database was developed according to the following general steps: (1) the road system was represented by a database of road segments or links, and intersections or nodes. The linear topological relationships between links (joined by nodes) were stored in the database. Each link was coded with an attribute representing impedance to travel along it, which in this case was determined by an estimated travel speed and length of the link; (2) hospital locations were assigned to the nearest node and coded according to the supply of available hospital beds; and (3) patient demand for services was derived from the zip code–aggregated patient discharge data and distributed throughout the road links within each zip code.

The road network was generated from the U.S. Census Bureau's 1992 TIGER/Line files. The road links were extracted for each of the 16 counties in the study area and imported into the GIS database where all of the counties were merged into one data layer. Automated edge-matching was performed on the road links to ensure that the road system continued across county boundaries. Linear topology was built for the entire data layer resulting in a network database with 184,216 road links summing to approximately 110 mb in size. The TIGER Census Feature Class Code (CFCC) for each link was used to estimate an average travel speed for the link. Total travel time along the link was derived from the estimated speed and the length of the link.

The 25 hospitals in the study area were geocoded using the ITRE street address database mentioned before; it had been spatially matched to the TIGER data by ITRE, prior to its acquisition for this research, and it contained significantly higher percentages of complete address ranges, making automated address geocoding possible. After geocoding, hospitals were assigned to the nearest node in the road network using a proximity analysis, and their supply of resources was coded according to the number of available beds listed in the American Hospital Association's *Annual Survey of Hospitals* for 1992.

Patient data from the North Carolina Medical Database Commission were imported into the GIS database. Since zip codes can refer to either points or areas, patient population values for point zip codes were aggregated to the surrounding areal zip codes. The ARC/INFO Network analysis module requires that the demand within the network system (i.e., the patient discharge data) be represented along the network's road links (the idea is that each patient's trip to care originates along a road, not at a zip code centroid). Therefore, an overlay operation was performed to relate the polygonal zip code patient discharge data layer to the road network, and each road link was coded with a proportion of the patient population data for the corresponding zip code. The proportion was calculated based on the ratio of the link's length to the total length of all the links within that zip code. This proportional value was also standardized to represent a single day's worth of the patient discharge data, creating a "snapshot" view of patient demand for hospital care resources.

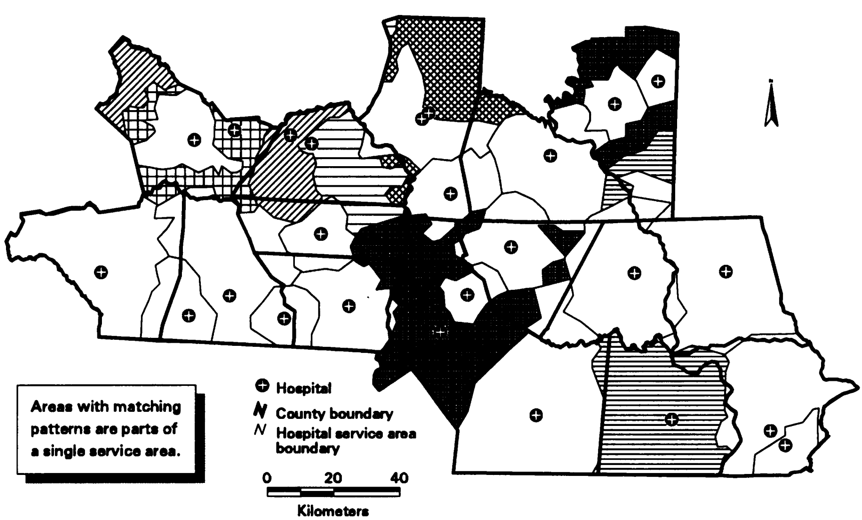
The actual network analysis was performed using the automated allocation procedures of the GIS. Patient population values assigned to road links were assigned to the nearest (in terms of travel time) hospital with available beds. The allocation algorithm (Environmental Systems Research Institute 1992) worked outward from each hospital, assigning links and their associated patient populations to the nearest hospital until its resources were exhausted or until all patients were allocated.

RESULTS

The allocation process within the Network analysis generated normative service areas; that is, they represented what the service areas "should be" to ensure geographic efficiency through travel time optimization. In this case, efficiency was based on minimization of travel time to care from patient addresses (at the zip code level). This normative orientation is in contrast to the services areas empirically derived from hospital use indexes (e.g., Commitment, Relevance, and Coverage Indexes) reported by Gesler, Walsh, Crawford, et al. (1995).

Figure 2 shows the hospital service areas derived through the Network analysis for the 25 hospitals in the study area using a 1991 patient discharge population. The thinner black lines represent the service area boundaries; these were digitized based on the geographic extent of the road links allocated to each hospital. (Note that the results of the Network analysis are generally represented through color-coded graphics where each road segment allocated to the service area for each hospital is represented in a similar color.) The distance minimization goal of the allocation algorithm produced generally circular service areas surrounding each hospital. In some instances, however, the derived service areas were disjointed or fragmented and separated by sizable distances. This pattern is the result of smaller, rural hospitals that (within the Network analysis) do not have a sufficient number of available beds to serve the patient populations in their immediate vicinities. For example, the two adjacent small hospitals in Davidson County (in the northeastern portion of the study area) are flanked by two partial areas allocated to larger hospitals in highly urban Mecklenburg County and in rural Anson County.

Figure 2: 1991 Patient Population, Network Analysis Service Areas

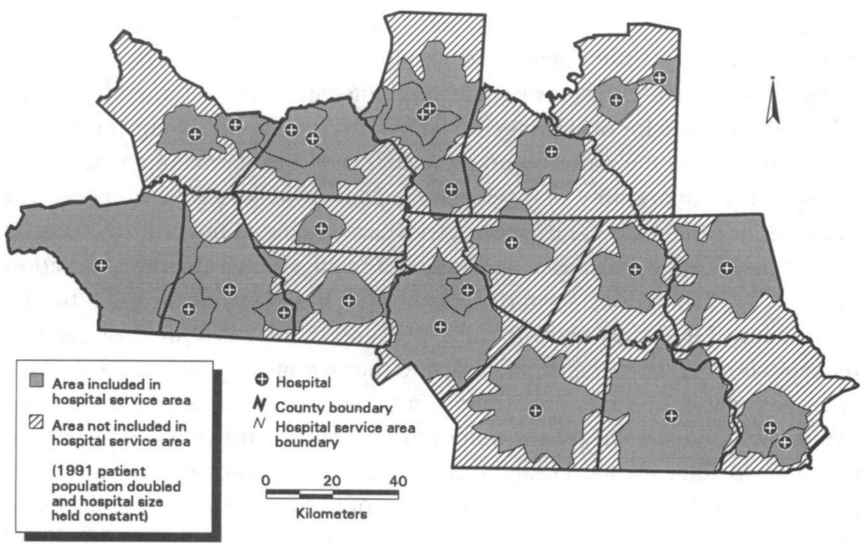


Patients within these areas have poorer access to healthcare in this normative model of hospital service areas.

As a consequence of the patient allocation, patients in Davidson County (upper right corner or northeastern portion of the study area), for example, are required to commute for nearly two hours to the Mecklenburg and Anson County hospitals for care. Other instances where patients were allocated to distant hospitals are evident. Travel times are dependent on the topology of hospitals, transportation patterns, population characteristics, and bed assignments within the allocation process. As previously stated, during an allocation of patients to hospitals for actual healthcare planning purposes, a buffer of hospitals and counties would be developed and integrated with the core counties and hospitals of primary study to allow for movement of patients within the study counties to hospitals outside the region and for patients outside the region to migrate to study area hospitals during the allocation process.

Figure 3 shows the results of the Network analysis when the 1991 patient discharge levels are doubled (x 2) for each hospital, while hospital size (i.e., the number of available beds) is held constant. As would be expected, the

Figure 3: 1991 Patient Population x 2, Network Analysis Service Areas



service areas surrounding each hospital areally constrict when the Network analysis allocation procedure is rerun with this alternative demand condition. A substantial proportion of the actual 1991 patient population comes from zip code areas immediately adjacent to the hospital (primarily the case of the urban hospitals, and to a less degree for the rural-to-urban transition and rural hospitals). Large areas of the study area not allocated to any of the 25 hospitals under the travel-time-to-care minimization goal of the allocation and the existing supply of hospital beds. Such unallocated areas could be designated as "unserved." Because hospitals are located within the urban areas of each county, it is largely the rural population of the study area that is left unallocated within this simulation that would be required to travel considerable distances to receive care (Thouez, Bodson, and Joseph 1988). It is unlikely, however, that in a "real-world" situation the demand for healthcare would double for all zip codes, and that it would occur with no increase in the number of facilities and/or number of available beds. The simulation was used to explore the spatial implications of accessibility scenarios as an aid in healthcare planning by altering patient demand.

Hospital service areas were also defined through Network analysis for patients associated with DRG number 391, Normal Newborns. Only 19 hospitals were involved in the analysis, because six hospitals within the study area did not offer obstetrics care. By selecting patient populations based on their care procedures (i.e., DRG codes), number of beds associated with each hospital, and the type of care allocated to each bed, it is possible to perform analyses of service areas for particular types of care, for example, certain obstetrics services only. Generated service areas were locally configured, requiring low travel times for patients seeking care at the assigned hospitals. When the demand for obstetrics care (DRG 391) was doubled, however, only minor changes in the pattern and areal extent of the service areas resulted. The spatial comparability of service areas derived for the 1991 demand and for a doubling of the demand for obstetrics care suggests a possible oversupply of beds assigned to obstetrics care within the study area for the simulation scenario. As in previous scenarios, the model has been constrained by the boundaries of the study area, thereby preventing the movement of patients to hospitals external to the study area, and the passage of patients living in zip codes outside of the study area to hospitals inclusive to the study area. Some service areas, particularly at the outer margins of the study area, experienced a change in their spatial configuration as a consequence of a doubling of demand, thereby suggesting an uneven supply and demand for obstetrics care throughout the region and the availability of obstetrics care outside and adjacent to the defined 16-county region. Of course, it is unlikely that demand for obstetrics care or care for other DRGs would be distributed in the identical pattern and fashion as seen in the 1991 patient discharge data. For simulation purposes, the assumption of a doubling of demand and a mirrored distribution of the demand was deemed acceptable to the objectives of the study.

DISCUSSION

The study reported on here is normative; that is, it allocates populations to hospitals based on what "should be" in terms of a specific criterion: minimizing consumer travel time, given existing healthcare resources (hospital beds), demand for services (population size), and interactions between supply and demand (impedances along transportation linkages). Normative scenarios obviously depart from actual healthcare utilization patterns for many reasons, including service mixes, consumer perceptions about the quality of their treatments at hospitals, availability of transportation, consumer and physician preferences, managed care contracts, and so on. However, normative studies have their uses. They set a standard that can be compared to real-life situations and thus may lead to alterations that could, for example, lead to more equitable allocation of resources. Once normative models are established, they can be altered in many ways to investigate what happens when the healthcare delivery system is "perturbed" by, for example, adding new beds to a hospital, closing a hospital, population increases or decreases within the study area, improving a section of the road network, and so on. We have indicated some possible future scenarios here. We have also shown what effect normative scenarios and changes in these scenarios have on accessibility for various population subgroups.

The spatial patterns of the defined service areas can be related to U.S. Census variables to profile the served, unserved, and underserved population and population subgroups defined through the Network analyses. Sociodemographic data detailing, for example, per capita income, race, and gender, can be used to describe population characteristics associated with defined service areas (and areas outside the derived service areas) mapped over time and space. Such profiles can be used to interpret and/or evaluate the spatial-population implications of the supply, demand, and impedance variables integrated within the GIS–Network system. Various levels of census geography (e.g., block group and zip code) can be used to aggregate population characteristics for population profiling and to spatially relate them to the pattern of the service areas.

Those endeavoring to reproduce the methodologies employed here for the first time will encounter, as the authors did, several frustrations. The requisite data may be difficult to obtain. Manipulating the data sets is a time-consuming task. There is a fairly long learning curve involved in the proper use of GIS such as ARC/INFO software. However, short-term difficulties have long-term payoffs. Furthermore, training in the use of ARC/INFO and other GIS software is increasing rapidly, so the requisite expertise is fast becoming available. In addition, sophisticated modeling software such as Network analysis is now becoming part of desktop mapping software and therefore is becoming increasingly available to healthcare planners. Once the system is up and running, the scenarios that can be produced are relatively limitless. As examples, criteria other than travel time can be introduced or runs can be made for specific DRGs.

The debate about healthcare reform is taking place in the midst of a bewildering variety of changes in the U.S. healthcare delivery system. The introduction of HMOs and PPOs in recent years, and the development of physician and hospital networks, have greatly altered the health care landscape. How is one to make sense of all this? GIS helps to bring some spatial order into this chaos. The danger, of course, is that GIS will be used to the exclusion of other types of analyses (e.g., consumer satisfaction or treatment outcome studies). Nevertheless, healthcare planners are required to manage large data sets and the methods advocated here are a rational way of doing this. Normative models based on GIS technology thus become a valuable tool in the planning process. One particular direction in which healthcare planning is going is toward development of regions composed of interacting hospitals and physicians. The Network analysis models discussed here are particularly useful for analyzing healthcare delivery within these regions.

Normative GIS models have many specific uses. Spatial simulation procedures can be utilized by hospital administrators and healthcare planners to assist in incorporating increased access to care in planning for a region's future healthcare needs or to show how restricting providers (e.g., HMO or PPO) affects geographic access. The Network analysis can be iteratively run to reflect changes in the transportation network (e.g., construction of new roads, changes in speed limits, alternative modes of transportation), hospital characteristics (e.g., number of beds, referral patterns, and managed care alliances), and other factors influencing healthcare accessibility within the Network analysis. Further research will include an investigation of ways to incorporate actual physician-to-hospital referral linkages in the GIS for healthcare accessibility studies.

CONCLUSIONS

The GIS approach to assessing healthcare accessibility places hospitals, patient origin locations, transportation arteries, and intervening opportunities within a spatial context where trajectories in the healthcare system and community characteristics can be simulated. The spatial database and the automated analytical system afforded through the ARC/INFO software can incorporate actual planning of healthcare accessibility as well as alternative scenarios in which the redistribution of supply and demand are simulated through Network analysis. The GIS–Network system was demonstrated in this research to be an important tool for assessing the spatial linkages between healthcare users and providers and for examining possible healthcare planning scenarios where the interaction of population, facility characteristics, and transportation networks is spatially mediated. The GIS–Network approach may be even better suited to analyzing and allocating lower-level care services, such as primary care or rural health clinics where geographic distance is clearly a constraining factor in healthcare accessibility.

The spatial pattern of the service areas was defined through the Network analysis for (a) the 1991 patient population, (b) the simulated doubling of the population, (c) the 1991 obstetrics care population, and (d) the simulated doubling of the obstetrics population. Sociodemographic characteristics of the population designated as served, unserved, or underserved through the simulations can be examined through use of U.S. Census data by profiling populations for specific areas and for various levels of census geography to aid in understanding the spatial and demographic implications of healthcare scenarios.

Despite the limitations of using GIS-generated models, including the use of normative models in general and the financial outlays and expertise required, these models have been shown to have specific uses for healthcare planning. Once developed, they can be rerun relatively rapidly to take into account many system variables related to healthcare resources, patient populations, and transportation networks.

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